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Flight Trial Demonstration of Seamless Aeronautical Networking

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Abstract: This article presents the inflight demonstration of a new integrated aircraft communications system combining legacy and future radio technologies. Developed and validated under real environment conditions during flight trials, this system integrates all the aeronautical service domains within a common IPv6-based aeronautical network. The flight trials were held within the framework of the European SANDRA project at Oberpfaffenhofen, Germany in June 2013. The presented outcomes will emphasize the flexibility and scalability of the developed network and demonstrate the seamless service coverage of the given architecture across different airspace domains[1].

Keywords: Flight trials, Seamless Aeronautical Network, IPv6, AeroMACS, BGAN, VDL2.

1. Introduction

Aeronautical communications are currently facing a continuous increase in capacity demand. This ceaselessly request for more communication capacity is on the one hand due to the constant growth in the number of passengers and thus aircraft, expected to double by 2035 [1], but also due to the introduction of new aeronautical communication services with high data volume demand. The latter comprise, among others, new operational safety-critical services such as 4D-Trajectory as well as non-safety critical services like wireless in-cabin connectivity for passengers. To cope with this high demand in communications capacity, part of the ongoing research aims at developing new concepts and technologies for future aeronautical communications (like the European SESAR Joint Undertaking program [2] and the FAA Next Generation Air Transportation System (NextGen) [3]), with a strong emphasis on the development of new link technologies, such as the terrestrial L-band Digital Aeronautical Communications System (L-DACS) link [4], and the European Space Agency (ESA) Iris program [5].

The introduction of new digital communication links is of paramount importance in the aeronautical sector as the existing Air Traffic Management (ATM) communication

[1] The material in this paper was presented in part at DASC 2013, Syracuse, NY, USA

infrastructure already operates close to the maximum capacity [6]. However, although the new systems will eventually replace the legacy communications systems, there will be a lengthy period where aircraft will be fitted with all of the systems for global interoperability. Hence, there is a need to integrate legacy and future data links into one large seamless aeronautical network to serve the future communication demand.

The design, development, and validation of such a seamless network correspond to the focus of the European funded research project SANDRA (Seamless Aeronautical Networking through integration of Data links Radios and Antennas) [7], which integrates different communication links (legacy and future data links) and networks (such as ATN/OSI or ATN/IPS) with all the aeronautical service domains (ATS, AOC/AAC and APC) in a safe, high-performance and cost effective way, having IPv6 as unification point. The development of the entire corresponding ground network infrastructure is also part of the SANDRA architecture. The validation of the latter has been realized by performing flight trials on the airport of Oberpfaffenhofen close to Munich, Germany [8]. This paper gives an overview of the first SANDRA flight trials outcomes with a strong emphasis on the seamless handovers that have been carried out between legacy and future data links, namely VDL2, BGAN and the newly developed AeroMACS [9], and therefore, proving the flexibility and scalability of the SANDRA network. The seamless service coverage aspect of the SANDRA architecture has been demonstrated by the successful test of various applications in all aeronautical service domains.

The rest of the article is organized as follows. The SANDRA concept is introduced followed by the overall system setup and details of the most relevant components. The flight trials, its main results regarding handovers, network technologies, and used applications are presented.

Glossary

AAC	Airline Administrative Communications	BGAN	Broadband Global Area Network by Inmarsat
AeroMACS	Aeronautical Mobile Airport surface Communications	CLNP	Connectionless Network Protocol
AOC	Airline Operations Center	IDRP	Inter-Domain Routing Protocol
APC	Aeronautical Passenger Communication	IPS	Internet Protocol Suite
ATN	Aeronautical Telecommunication Network	OSI	Open System Interconnection
ATS	Air Traffic Service	VDL2	Very high frequency (VHF) Digital Link mode 2

2. The SANDRA Concept

The vision of SANDRA is the integration of aeronautical communications systems using well-proved industry standards to enable a cost-efficient global provision of distributed services. SANDRA system is considered as a ‘system of systems’ addressing four levels of integration: Service, Network, Radio, and Antenna.

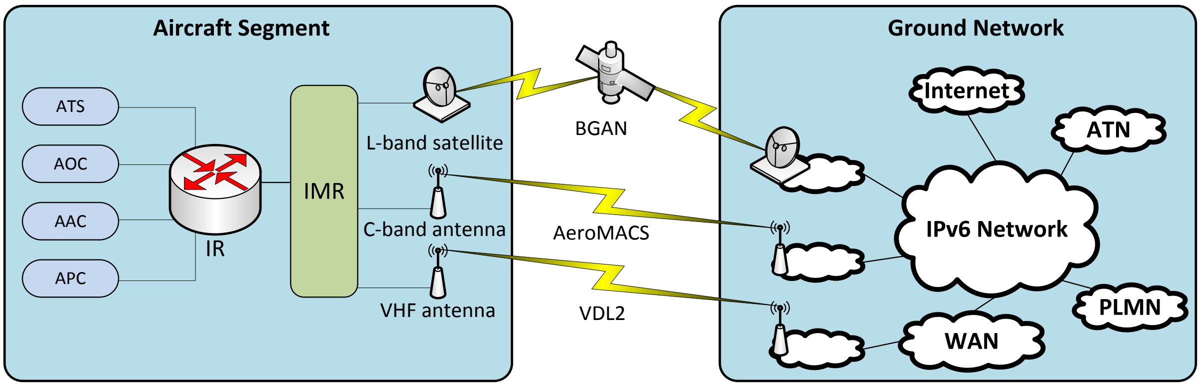


Figure 1. SANDRA Flight Trial Network Architecture

Considering the communications network, SANDRA spans across two segments, i.e., aircraft segment and the ground segment, as shown in Figure 1. The aircraft segment for the flight trials contains the main functional components: the Integrated Router (IR), the Integrated Modular Radio (IMR) and the antennas consisting of a satellite L-band antenna (BGAN), a VHF band antenna, and a C-band antenna for AeroMACS. Details about the SANDRA ground network are given in the following section.

3. System Setup

The system setup of the SANDRA flight trials is composed of two major segments, namely the airborne segment and the ground infrastructure.

3.1 Airborne Segment

The SANDRA airborne system has been integrated in an Airbus A320, displayed in Figure 2.

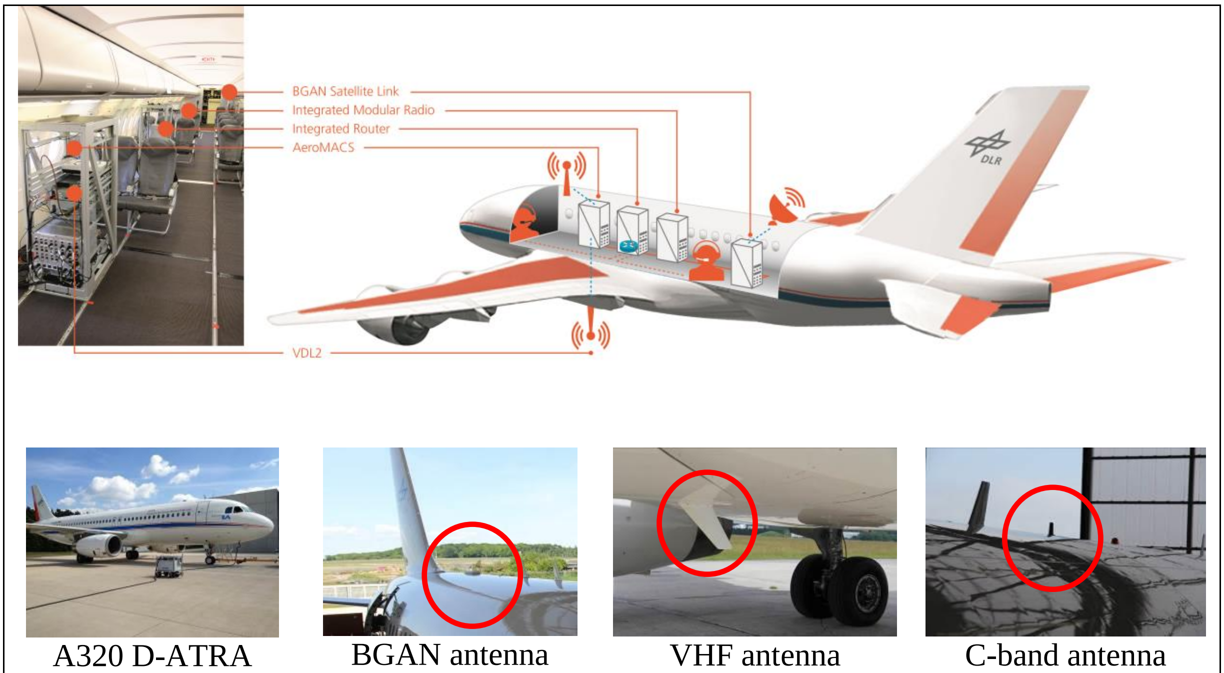


Figure 2. SANDRA Airborne System installed at an A320 including the experimental antennas

As to the data links, 3 different radio technologies were integrated in the aircraft, namely BGAN, VDL2, and AeroMACS. The aircraft was already equipped with a BGAN and a VHF antenna (used to test VDL2), located on top at the rear of the fuselage and in the middle below the fuselage, respectively. The AeroMACS C-band antenna has been especially mounted on top of the fuselage for the SANDRA flight trials. The inline figures of Figure 2 show the positions of the BGAN, VHF and AeroMACS antennas on the fuselage of the aircraft.

In order to be integrated in the aircraft, the SANDRA airborne system has been divided into 4 separate racks containing different pieces of equipment, as illustrated in Figure 2. The distribution of equipment within the racks was based on the different functionalities whereas the locations of the racks within the cabin were defined based on the positions of the antennas on the aircraft's fuselage. The racks were organized as follows. The first rack contained the Integrated Router and the connectivity to the different end-user systems. The second rack was equipped with the two Integrated Modular Radio processing platforms, representing thus the link between the IR and the different RF equipment (one IMR used as redundancy back-up). The third rack was fitted with the RF units for the VDL2 and AeroMACS data links. Finally, the RF components handling the BGAN satellite link were located in the fourth rack at the rear of the cabin. So as to reduce as much as possible the antenna cable losses, the third and fourth racks were placed in the cabin right below the respective antennas.

3.2 Ground Infrastructure

The core part of the SANDRA ground infrastructure was located at Oberpfaffenhofen, Germany. It comprised all the IP-based networking components such as the Access Router and the Home Agent. Whereas the latter includes functionalities like IPsec (IPv6) to provide authentication and integrity and the NEMO protocol [10] to guarantee mobility to the airborne terminal, the former integrates an IPv6-over-IPv4 transition mechanism, entitled NeXT [11]. The Access Router also provides the router advertisement messages (ICMPv6) required by NEMO on the Integrated Router. This message is part of the Neighbor Discovery Protocol (NDP, RFC 4861). The SANDRA network provides connectivity not only to the different ground end systems but also to the ATN, the Internet, and to the Public Switched Telephone Network (PSTN, for passenger communication), enabling ATS (communication with Air Traffic Control (ATC)) and AOC services (business communication of the airline), as well as APC (e.g., for Internet access and mobile telephony) and airline non-operational services (AAC).

About the ground infrastructure of the data links, two different base stations have been specifically installed for the SANDRA flight trials, namely a VHF Ground Station (VGS) and an AeroMACS base station. The latter was installed on top of a hangar building overlooking the Oberpfaffenhofen airport. Connectivity between this base station and the SANDRA laboratory has also been established via a VLAN. The antenna used for the AeroMACS base station was a directional antenna (90°) with a focus on the aircraft parking position. Furthermore car tests have been carried out at the Oberpfaffenhofen airport so as to estimate the received signal level from the AeroMACS base station. A C-band antenna has been mounted on the roof of a research vehicle. Thanks to the use of a spectrum analyzer, the signal level could be estimated on the runway, taxiing path, and parking position of the aircraft.

Finally as to the ATN/OSI ground infrastructure, a VGS for VDL2 has been installed on the roof of SANDRA laboratory close to the airfield, although the ATN/OSI ground end system was located at Montreal, Canada and connected to the SANDRA laboratory via a Wide Area Network (WAN). The satellite connection was made over the BGAN satellite network. More exhaustive insights on the SANDRA ground infrastructure as well as on the overall SANDRA test-bed can be found in [12].

3.3 Oberpfaffenhofen Airport

The SANDRA flight trials occurred from 24-26 of June 2013 at Oberpfaffenhofen airport (EDMO), Germany. This airport consists of one single runway. The parking position of the aircraft was in direct Line-of-Sight (LOS) with the AeroMACS base station and the VGS.

4. Flight Trials Results

4.1 Flight Sorties Description

In total, 6 sorties in 3 days have been made with the D-ATRA aircraft at a rate of 2 flights per day (one in the morning and one in the afternoon). The focus of the first day was mainly to evaluate the correct data transmission over the air for each of the 3 data links. Once the links were operational, the flight trials of the second and third day aimed at validating the SANDRA concept by performing a set of scenarios previously identified. In order to do so, various applications ranging from ATS over AOC, AAC to APC services were tested onboard the aircraft.

On average, each sortie lasted roughly 90 minutes including taxiing, take-off, and landing phases. The scenarios were performed onboard during the 45 minutes of cruise. For each sortie, the aircraft was flying over Oberpfaffenhofen airport and continuing its route until the VHF connection was lost. Once out of VHF coverage, the aircraft was turning around to fly back over Oberpfaffenhofen airport and thus reentering the VHF coverage. This back-and-forth route over the airport allowed testing the seamless functionality of the SANDRA concept

4.2 Seamless Aeronautical Networking Analysis

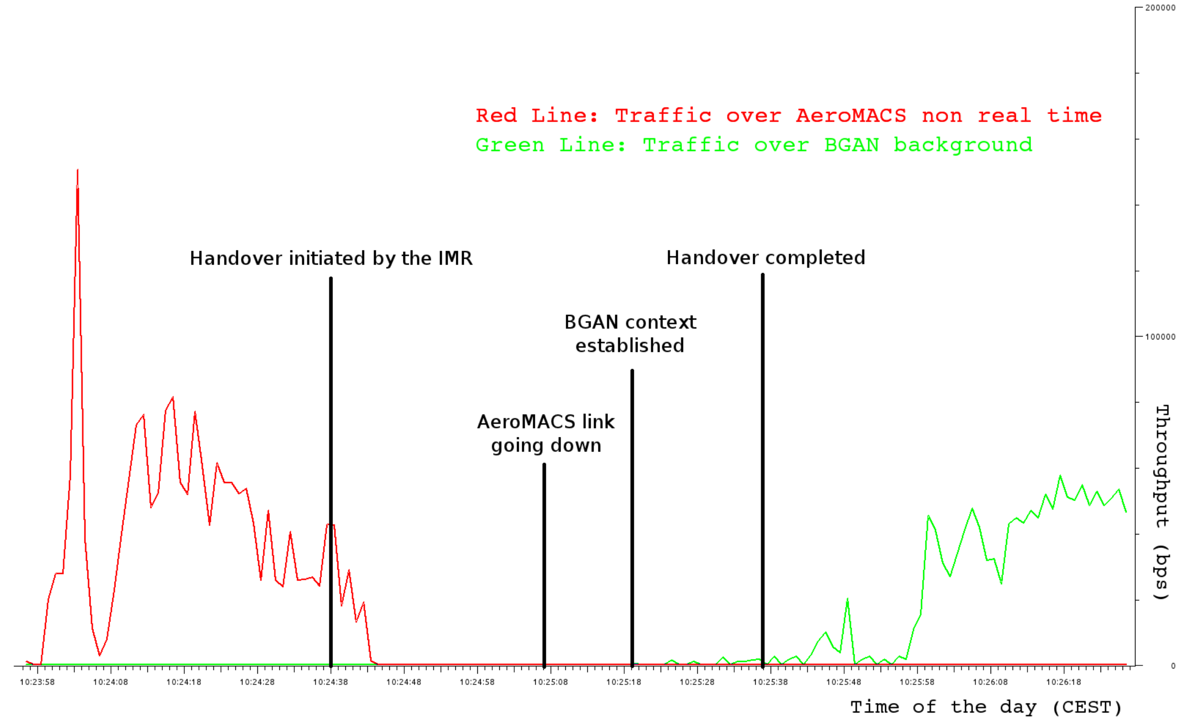
Various specific scenarios have been performed during the flight trials to demonstrate the seamless aspect of the SANDRA network.

4.2.1 Seamless Layer 3 Handover

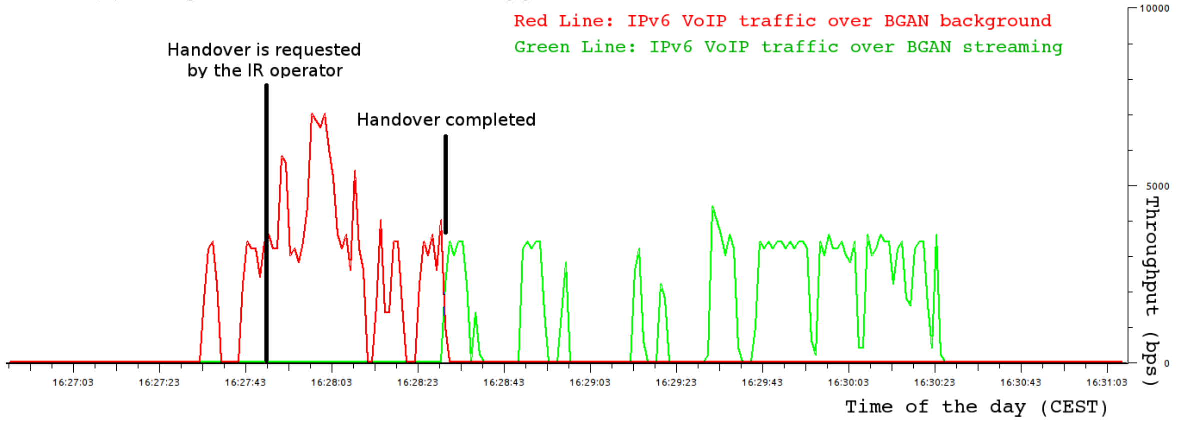
Whenever a change of traffic routing policy involving two different data links occurred, a handover was performed. During the flight trials handovers were performed between all three link technologies in both directions (e.g., BGAN to VDL2 and VDL2 to BGAN) and also between some combinations of different quality of service contexts within the same technology (BGAN background to BGAN streaming). Additionally, the handovers were classified depending on the triggering condition. One type was the “IMR triggered handover”, initiated by the Integrated Modular Radio when the aircraft was moving (or was already) out of coverage of one of the available links. The other type, the “IR triggered handover”, was a handover caused by the human operator changing the policy routing on the Integrated Router.

In order to test the “IMR triggered handover”, an AeroMACS context was open while the aircraft was in parking position. Once set, traffic was generated from the end systems to put some load on the link. Then, the IMR was told that the aircraft was changing from a “standing” position to “en route”. Since AeroMACS is not available while the aircraft is cruising, the IMR initiated the procedure to open a new BGAN context and notified the IR of the upcoming change. Figure 3(a) shows the handover and how traffic is sent over BGAN again after the handover is completed.

An “IR triggered handover” can be observed in Figure 3(b). Initially, all traffic is sent over a BGAN background context. While this best-effort type of service is good enough for applications like browsing or e-mailing, it’s not suitable to jitter sensitive applications like voice-over-IP (VoIP). For that reason, the IR operator requested a change on policy routing. Instead of interrupting the traffic upon the request, traffic is routed through the new context only after this has been completely established, therefore avoiding an interruption of the communication. The VoIP call members did not notice any loss of communication and in fact, no packets were lost during the handover and only one packet suffered reordering.



(a) Integrated Modular Radio triggered handover from AeroMACS to BGAN



(b) Integrated Router triggered handover for VoIP

Figure 3. Triggered handover performances

4.2.2 Seamless Layer 2 Handover

The IMR, which represents the data-link and physical layer of the OSI stack, consists of the different radio protocol stacks (AeroMACS, VDL2, and BGAN). Furthermore, it includes an adaptation layer called Joint Radio Resource Manager (JRRM) that is responsible for managing and controlling the underlying radios in a uniform and consistent manner and provides a single interface to the network layer.

To increase the assurance of the IMR, there are two JRRMs running simultaneously with one on each IMR processing platform, IMR-PC1 and IMR-PC2 respectively. At any time, there is one and only one JRRM acting as the Master and in charge of all the processing while the Slave JRRM keeps on synchronizing with the Master. Different time recordings for the hot swap process (when the Master JRRM was terminated and the Slave JRRM swapped as new Master) could be done during flight trials. The data tunnel switch time indicates the time window that data cannot be transmitted. This time was varying between 170ms and 184ms. Whereas, the overall switch time is the time starting from when the Slave JRRM detects a failure of the Master till all sub-modules complete the switching process. Here, the maximum recorded time is 286ms and minimum time is 180ms. Thanks to the multi-core and multi-threading programming technique, there is not much difference on the time required for processing single or multiple data tunnels.

It took slightly longer time for the switch process to complete if radio stacks are running on the same processing platform with the new Master JRRM to be due to the computing resources shared between the JRRM and radio stacks. Similarly, the switching time is affected by the data tunnel traffic load, the heavier the user traffic, the longer time it will take.

Figure 4 shows the time required for session establishment from randomly selected BGAN and AeroMACS sessions during the flight trial. The session establishment time means the overall time of a session establishment from reception of the session open request till the data tunnel is completed ready for data transmission. In order to express the processing time required by the JRRM more precisely, the processing time in JRRM only measures the time used within the JRRM modules excluding the radios stacks layer two processing time, such as ranging, registration or attachment time. The minimum session establishment time being seen is 3.02 seconds where the satellite terminal has already registered and attached to the network before session open request and the maximum time being seen is 22 seconds where a fresh network registration, attachment has to be done in order to setup and activate the Packet Data Protocol (PDP) context for the open request. On the other hand, the AeroMACS session establishment is much quicker; it takes less than 1 second to complete a data connection with the ground station. However, the session establishment processing time used within the JRRM for BGAN and that for AeroMACS have the same order of magnitude despite the big overall difference in their end-to-end connection establishment due to the fact that JRRM treats all waveform equally in a uniform way.

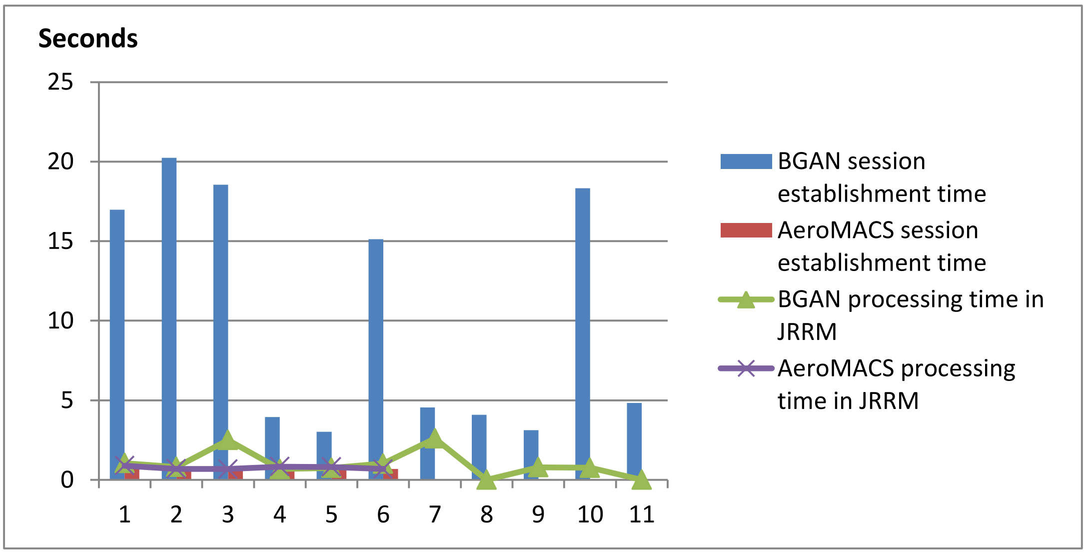


Figure 4. Session establishment time

4.2.3 ATN/OSI over IP-SNDCF

The use of IP Sub-network Dependent Convergence Function (SNDCF) enables the ATN/OSI upper layers and network (CLNP-IDRP) protocols to be conveyed over IP protocol. This allows IP-based networks to be used to provide the underlying ATN sub-network links between ATN routing entities. It was decided within SANDRA to experiment the use of IP-SNDCF on the aircraft (whereas today it is only used on ground), thus on a mobile system. The objective was to assess if ATN/OSI CLNP packets could be conveyed over VDL2 (as done today) and over SANDRA broadband radio IP links, in a seamless way. The advantage of a mobile IP-SNDCF is that avionics and ground stations can implement a single (or multiple but standardized) SNDCF for all mobile communication technologies instead of having different interfaces for each technology which is the case at present.

A prototype Mobile IP-SNDCF module was developed and integrated on existing ground architecture, as well as on the aircraft. This allowed demonstrating end to end ATN/OSI communications over VDL2 and SANDRA mobile IP implementation over BGAN and AeroMACS [13].

4.3 Aeronautical Service Coverage

Table 1 reveals the different applications that have been successfully tested on ground and in cruising phase so as to validate the SANDRA concept. As can be seen in Table 1, applications from all the different aeronautical service domains have been tested during the flight trials, emphasizing the seamless service coverage of SANDRA. As to the airborne end-system, most of the applications have been tested using a notebook or tablet directly connected to the Integrated Router either via Ethernet cable or via in-cabin Wireless Local Access Network. Their counterpart on the ground had various locations such as the SANDRA laboratory or the different internet servers. In the following, various applications of different service domains will be highlighted concerning safety relevant data, voice communication in the cockpit, airline operations services, and cabin communications.

Table 1. List of applications tested during the SANDRA flight trials

Application	Domain	airborne end-system	ground end-system	ground end-system location
AMBEATC10B VoIP	ATS	VoIP HW	VoIP HW	SANDRA lab
CPDLC ATN/OSI apps.	ATS	CMU Notebook	ATN ES	Montreal
Generic CPDLC tool	ATS	Notebook	Notebook	SANDRA lab
Electronic flight information bulletin	AOC	Notebook	server(s)	Internet
web chart application	AOC	Notebook	server(s)	Internet
web flight planning application	AOC	Notebook	server(s)	Internet
Electronic Flight Folder	AOC	Notebook	Notebook,	SANDRA lab
Flightstrips	AAC	Notebook	Notebook	SANDRA lab
Generic arrival/departure manager	AAC	Notebook	Notebook	SANDRA lab
Telemedicine	AAC	telemedicine tablet	telemedicine server	Internet
VoIP call	APC	VoIP mobile	VoIP Handset	Internet
web browser	APC	tablet	web server	Internet
email	APC	tablet	Email Server	Internet
Skype™	APC	tablet	Skype™	Internet

4.3.1 AMBEATC10B VoIP

The AMBEATC10B VoIP is an experimental hardware voice-over-IP appliance based on the AMBE ATC 10B vocoder circuit board. This is currently the only digital vocoder certified for air traffic control. The circuit board is integrated with a micro-controller and installed in a rack-mountable case with a push-to-talk button. The micro controller board runs a customized version of the Linux operating system reading/writing voice samples from the vocoder board and sending/receiving them over the SANDRA network using User Datagram Protocol (UDP)/IPv6. Both the airborne and the ground appliance were equipped with commercially available ATC headsets.

The quality of service delivered by the SANDRA network for VoIP applications was evaluated using the AMBEATC10B VoIP appliance according to ITU recommendation P.80 "Methods for Subjective Determination of Transmission Quality". ITU P.80 defines a conversation opinion test. Two subjects engage in a set of previously arranged domain-specific conversations and rate them according to a defined scale. In addition the subjects were interviewed to better understand the rating. In the case of the SANDRA evaluation the conversations were constructed from the Air Traffic Control Simulation Speech Corpus [14]. Each conversation comprised six ATC phrases exchanged by the subjects. After the conversation each subject was asked to provide an opinion on the transmission quality (excellent=5, …, bad=1) and to indicate any difficulties understanding the conversation partner (yes=1, no=0).

The SANDRA evaluation comprised four different speakers and a total of 65 conversations (i.e., 390 phrases exchanged). This was limited by the flight time and the number of personnel available in the aircraft. It should be noted, that the participants were familiar with the transmission quality offered by DSB-AM systems. The subjective rating of the voice quality should therefore be understood as relative to the established ATC voice systems.

Four of the 65 conversations were interrupted by reconfigurations of the data-links. Handovers from the AeroMACS link to the satellite link were seamless and generally not noticed by the conversing subjects. The smaller round-trip delay of the AeroMACS system compared to the satellite link was, however, perceived. Occasional packet loss on the satellite link was noticed by the users by missing syllables in the conversations, but not perceived as a great problem.

The mean score over all conversations was 4.33 (excellent=5, good=4) on the airborne side and 3.93 (fair=3) on the ground side. The perceived lower audio quality of the ground users can be explained by the background noise in the aircraft that was included in the transmission. On the aircraft itself the background noise was attenuated by the headsets, providing the airborne user with a clear reproduction of the ground signal recorded in a quiet room.

4.3.2 CPDLC ATN/OSI Application

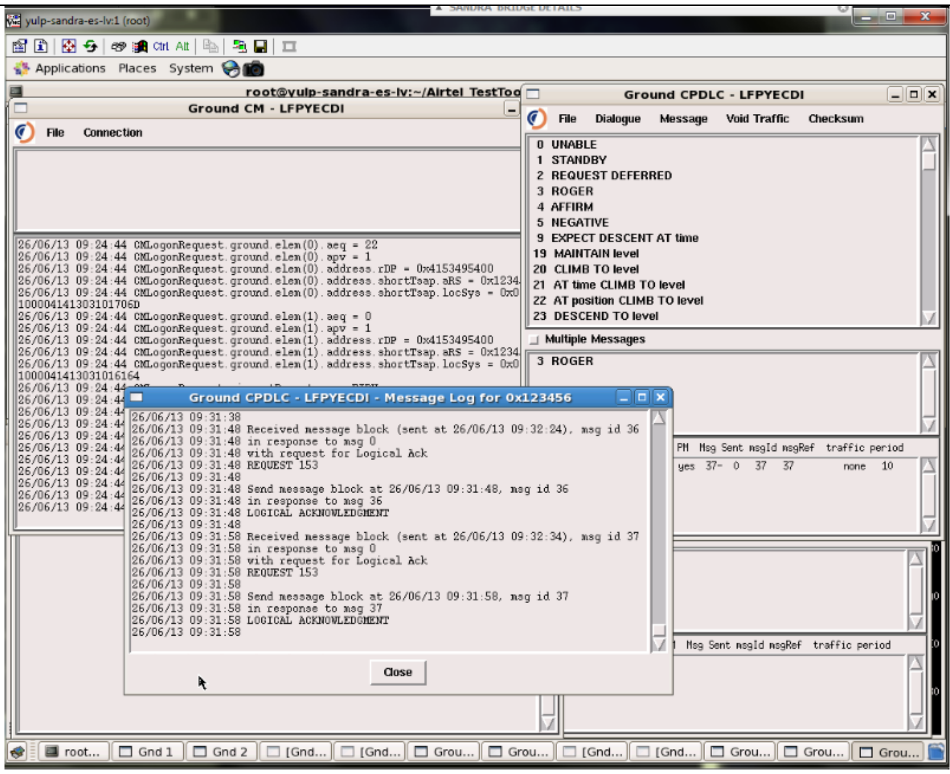
About the controller–pilot data link communications (CPDLC) ATN/OSI application, the ground end system was located in Montreal, Canada. During the inflight test of this application, a connection between the VGS on the ground and Montreal was established over the ATN/OSI ground network. The transmission of CPDLC messages was made over the VDL2 link. When the handover with BGAN (or AeroMACS) occurred, an IP connection through SANDRA ground network was established between the airborne and the ground end system in Montreal. The path for CPDLC messages switched thus from the ATN/OSI ground network to the IP-based SANDRA ground network. Figure 5(a) gives an example of CPDLC request exchanged every 10sec during first test on the 26th of June. One can notice that the LACK is received generally in 1sec (in IP over AeroMACS).

Context Management (CM) / CPDLC messages were routed seamlessly over one medium or the other, without any impact on the upper layers. During the flight tests, the IP path (BGAN or AeroMACS) was given priority and whenever both the VDL2 and the IP path was available at the same time, traffic was automatically routed over the IP path. When the IP path became unavailable, traffic fell back to using the VDL2 path.

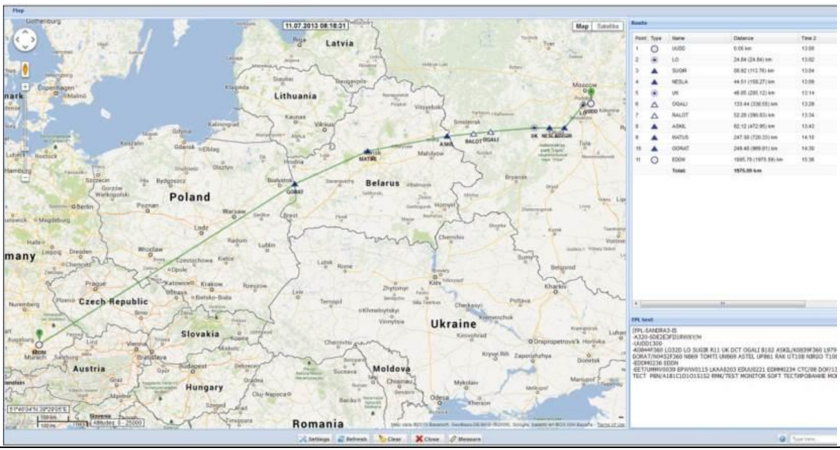
4.3.3 Airline Operational Services

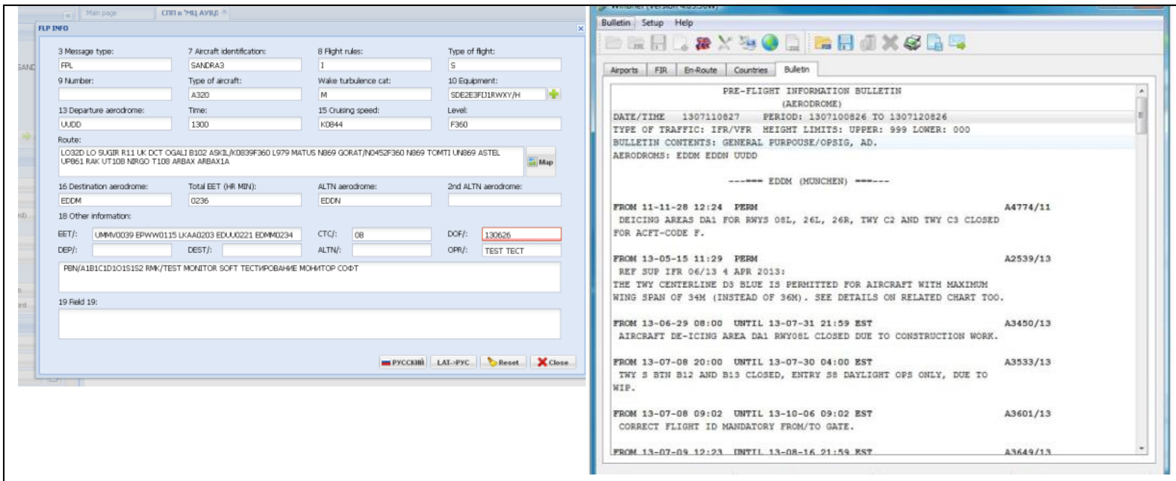
Covering also the airliner operational service domain, two applications are hereafter described. These applications have been integrated and tested during the flight trials. The first one aims at providing the crew members with the current changes taking place in the airspace and airports in a scope of a particular flight. The application receives basic flight details from a user and then requests all the Notice to Airmen (NoTAM) messages concerned from a central server. The output data is presented in ICAO format. Instead, the second application emulates a web service for both basic flight planning and submission of flight plan request to the state ATM authority. Along with the other features, this application provides a digital map with current aeronautical situation, automated route selection, and numerous flight plan checks.

A dedicated route, i.e., UUDD (Domodedovo, Moscow) -> EDDM (Munich), was first selected for such software tests, as depicted in Figure 5(b). The corresponding flight plan was successfully created and submitted. Then a positive response (approval) was received from the ATM service. And finally all necessary NoTAMs were requested and received regarding the chosen flight. All communication of both applications took place during taxiing and cruise phase. Despite some packets loss and consequent repeated requests in TCP/IP stack (which was not seen at application level) the software managed to communicate with the ground successfully.



(a) CPDLC request exchanges





(b) Web flight planning application with ICAO FPL form submitted and NOTAMs for UUDD-EDDM at time of flight trial

Figure 5. Examples of demonstrated applications.

4.3.4 Cabin Applications

Also real life passenger cabin applications were tested whilst in flight. This involved a number of passenger scenarios including surfing the Internet and sending and receiving emails through their Internet portal. With the aid of smart phones those in the air demonstrated social media posting and messaging as well as Skype^{TM} video and audio calls all through the SANDRA radios. A Patient Monitor unit was also demonstrated successfully for crew use, whereby a crew member and a doctor on the ground can simultaneously monitor the vital signs of a passenger whilst in constant audio communication through the SANDRA radio system.

4.3.5 Application's Performance over Future Data Link

Finally, having a closer look on the new integrated AeroMACS non-legacy data link, the end to end connectivity, affected not only by AeroMACS but also by all other networking systems (Integrated Router, Integrated Modular Radio, Access Router, Home Agent, etc.) has been verified using Internet Control Message Protocol (ICMP) Pings, with following measured delays: Min Delay = 33.314 ms, Max Delay = 265.054 ms, Average Delay = 76.823 ms, Standard Deviation = 32.172 ms and a packet loss rate measurement below 0.5%.

Different applications have been successfully tested using AeroMACS connectivity, in particular:

- AMBE ATC VoIP, both over Non Real-Time and Real-Time profiles, with an average 27 kbps throughput during voice transmission
- FTP transfer of a file from the ground, with an average throughput of 937 kbps
- ATN/OSI over IP-SNDCF traffic, with an average throughput of 0.5 kbps with peaks of 2.5 kbps
- Electronic Flight Folder traffic, with forward link traffic peak close to 1 Mbps, and average traffic below 300 kbps;

5. Conclusions

Within this paper, the flight trial outcomes of a new integrated aircraft communications system have been presented. Developed within the framework of the SANDRA project, this system has been integrated in an Airbus A320 and tested in real flight conditions in June 2013 at Oberpfaffenhofen airport, Germany.

During these flight trials, the two key features of the SANDRA concept have been demonstrated. On the one hand the seamless service coverage of the SANDRA architecture across different airspace domains was shown. Having IPv6 as unification point, it has been proven that this system integrates a full range of aeronautical applications (ATS, AOC/AAC, APC).

The second key feature of the SANDRA concept to be demonstrated during the flight trials was its global interoperability between legacy (VDL2, BGAN) and future data links (AeroMACS). This has been realized by performing first of all a handover on the ground between VDL2 and AeroMACS data links and secondly a handover while flying between VDL2 and the BGAN satellite link (for both cases, handovers have been performed in both directions). Transparent to the end-user, these handovers prove the interoperable and scalable aspect of the SANDRA network, which can switch reciprocally between legacy (non-IP) and future (IP) data links.

References

[1] EUROCONTROL: Fourth Study ‘Challenges of Growth 2013, Summary Report’ 2013, Available at: http://www.eurocontrol.int

[2] SESAR Joint Undertaking Program: http://www.sesarju.eu/

[3] FAA, NextGen Implementation Plan, March 2010.

[4] Brandes, S.; Epple, U.; Gligorevic, S.; Schnell, M.; Haindl, B.; Sajatovic, M., "Physical layer specification of the L-band Digital Aeronautical Communications System (L-DACS1)," Integrated Communications, Navigation and Surveillance Conference, 2009. ICNS '09, 13-15 May 2009

[5] Morlet, C.; Ongaro, F.; Ricard, N. & Santovincenzo, A. ESA Iris Programme: “Design options for the satellite communication sub-network of the European Air Traffic Management System”, Proceedings of the 29th DASC, Salt Lake City (USA), Oct. 3-7, 2010.

[6] EUROCONTROL/FAA: ‘Action plan 17 future communication study – final conclusions and recommendations report’. November 2007, Version 1.0. Available at http://www.eurocontrol.int

[7] Plass, S. “Seamless networking for aeronautical communications: One major aspect of the SANDRA concept”, Aerospace and Electronic Systems Magazine, IEEE, 27(9):21-27, September 2012

[8] S. Plass, R. Hermenier, P. Pulini, “SANDRA Flight Trials – Concept, Validation, and results,” Digital Avionics Systems Conference (DASC), 2013 IEEE/AIAA 32nd , 06-10 Oct. 2013

[9] J. M. Budinger and E. Hall, Future Aeronautical Communications. InTech, 2011, ch. Aeronautical Mobile Airport Communications System (AeroMACS), p. 28, Editor: S. Plass, ISBN 978-953-307-625-6.

[10] Devarapalli, V.; Wakikawa, R.; Petrescu, A.; Thubert, P.; “Network Mobility (NEMO) Basic Support Protocol”, RFC 3963, January 2005.

[11] A. Via, E. H. Fazli, S. Duflot; N. Riera, “IP Overhead Comparison in a Test-bed for Air Traffic Management Services,” Proceedings of the Vehicular Technology Conference 2009 (VTC 2009), Barcelona, Spain, Apr. 26-29, 2009

[12] O. Lücke, D. Depoorter, T. Tordjman, F. Kühndel, "The SANDRA testbed for the future aeronautical communication network," Integrated Communications, Navigation and Surveillance Conference (ICNS), 2013 , 22-25 April 2013

[13] F. O'Connor, F. Durand, “ATN/OSI over SANDRA mobile IP network: “A way to allow existing ATM solutions to leverage any broadband aircraft-ground link technologies,"

Integrated Communications, Navigation and Surveillance Conference (ICNS), 2013 , 22-25 April 2013
[14] Available at http://www.spsc.tugraz.at/tools/atcosim

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